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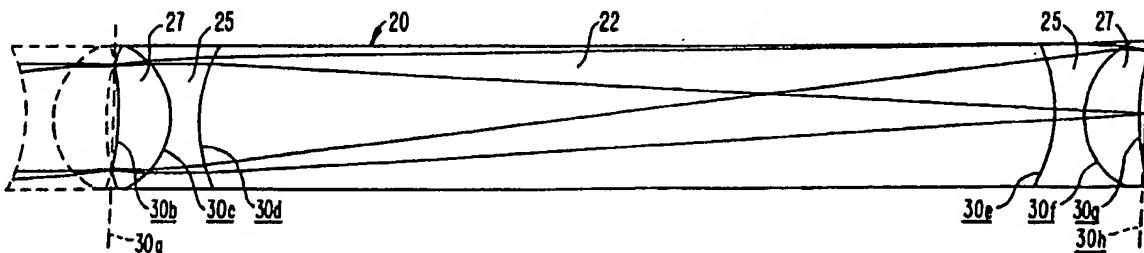


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(54) Title: ENDOSCOPE RELAY OPTICS



(57) Abstract

An endoscope relay optics design that reduces the number of air surfaces while maintaining high levels of correction. A lens assembly (20) for incorporation into an optical transfer system (where two such assemblies define an optical transfer module for transferring an image between successive image planes) is of unitary construction. The assembly comprises five elements including a central rod-like element (22) of high index material, a pair of negative elements (25) of relatively low index, high dispersion material cemented to opposite ends of the central element, and a pair of positive end elements (27) of high index, low dispersion material cemented to the negative elements. The powers of the elements are determined by requiring the Petzval sum to assume a desired low value, with index difference being the primary contributor to the correction. The two exposed surfaces are flat or mildly concave and include an aspheric component to correct spherical aberration.

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ENDOSCOPE RELAY OPTICS

5

CROSS REFERENCE TO RELATED CASES

This application is a continuation-in-part of copending U.S. Application, Serial No. 191,926 filed May 9, 1988.

10

FIELD OF THE INVENTION

The present invention relates generally to relay optics, and more specifically to endoscope relay optics.

15

BACKGROUND OF THE INVENTION

U.S. Patent No. 4,575,195, which is hereby incorporated by reference, discloses a series of endoscope relay optics characterized by the Petzval sum being corrected to a desired degree primarily by index difference, thereby avoiding any spaced high powered elements or sharply bent elements. Spherical aberration is corrected by providing aspheric surfaces on the exposed surfaces of negative plastic elements glued to positive glass elements. The design of the lenses discussed in the patent is very flexible and allows a high degree of correction so that the image quality at the eyepiece of the endoscope is high.

However, quality usually has its price, and the price in this case is a relatively large number of glass-air and plastic-air interfaces for most of the embodiments. Thus, while the lenses themselves are readily manufacturable in the sense of having relatively gentle surfaces, the cost of coating the large number of interfaces can be considerable.

SUMMARY OF THE INVENTION

The present invention provides an endoscope relay optics design that reduces the number of air surfaces while maintaining substantially the levels of correction that characterize the prior art endoscope optics referred to above.

A lens assembly for incorporation into an optical transfer system (where two such assemblies define an optical transfer module for transferring an image between successive image planes) is of unitary construction. For one set of examples, the assembly comprises five elements including a central rod-like element of high index, low dispersion material (typically having convex or flat surfaces); a pair of negative elements of relatively low index, high dispersion material cemented to opposite ends of the central element, and a pair of positive end elements of high index, low dispersion material cemented to the negative elements. The powers of the elements are determined by requiring the Petzval sum to assume a desired low value, with index difference being the primary contribution to the correction. The lenses are of symmetric configuration to correct coma, distortion, and lateral color, and the dispersions of the material are chosen to correct chromatic aberration.

In some examples, the two exposed surfaces are flat (but not abutting adjacent assemblies) or mildly curved and include an aspheric component to correct spherical aberration. In other examples, the exposed surfaces do not include aspheric components. Rather, aspherics are located along the interfaces between the positive end elements, and their abutting negative elements. In a limiting case, where the end surfaces are flat, they abut the flat end surfaces of the adjacent lens assemblies, whereupon the flat faces can be cemented, or adjacent end elements can be made unitary. In a further limiting case, the negative

elements and the central element can be formed of the same material, and can thus be unitary.

5 The present invention thus achieves a high level of optical correction and improved manufacturability due to the absence of steep curves and the small number of air interfaces.

10 A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an optical schematic of an endoscope showing transfer assemblies;

15 Figs. 2A-L are optical schematics of various examples of five-element transfer assemblies according to the present invention;

Fig. 3 is an optical schematic of a limiting case of the assembly of Fig. 2L;

20 Figs. 4A-C are optical schematics of other limiting cases; and

Fig. 5 is an optical schematic of a paired doublet assembly.

25 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is an optical schematic of an endoscope 5 in which the relay optics of the present invention may be incorporated. The system comprises an objective 10 for forming an image in a first image plane 12, a relay system 15 for transmitting an image in plane 12 to a second image plane 17, and an eyepiece 18 for viewing the transmitted image. Objective 10 and transfer system 15 occupy a relatively small diameter barrel which is typically surrounded by an annular 30 fiberoptics bundle. A typical diameter of the lenses 35 is about 2.5 mm.

In use, the endoscope is inserted within a body cavity or the like by a physician for viewing of internal body regions. Objective 10 forms an image of the region to be viewed at first image plane 12, which image is transmitted by relay system 15 to second image plane 17 proximate eyepiece 18 for direct viewing by the physician or communication to a television camera. In some of the examples to be discussed below, relay system 15 comprises a plurality of cemented 5 five-element assemblies 20. Assemblies 20 are arranged in pairs, with each pair providing a transfer module (i.e. a module which transfers an image from one plane at the front of the module to a second plane at the rear of the module). In certain limiting cases, the 10 entire relay system can be a single cemented assembly. 15

Figs. 2A-L are optical schematics of various examples of assemblies 20 illustrating the detailed design and construction thereof. A portion of a neighboring assembly is shown in phantom. Assemblies 20 are preferably identical and symmetric from end to end. Each assembly 20 includes a central rod-like element 22, first and second negative elements 25 separated by and cemented to central element 22, and first and second positive end elements 27 separated by the central and negative elements and cemented to the 20 negative elements. 25

The geometric characteristics of assembly 20 are defined by an entrance pupil plane 30a, a front surface 30b, a first cemented surface 30c, a second cemented surface 30d, a third cemented surface 30e, a fourth cemented surface 30f, a rear surface 30g, and an image plane 30h. It will be appreciated that entrance pupil plane 30a and image plane 30h would properly be referred to as an image plane and an exit pupil plane 30 for the other assembly in the module. 35

The geometrical and optical parameters for the examples of Figs. 2A-L are set forth in Appendices

1A-L, and utilize the nomenclature wherein surfaces designated A-H correspond to plane 30a, surfaces 30b-g, and plane 30h. Units are in millimeters, it being understood that the actual lenses are much smaller.

5 Although the values in the appendices provide an assembly length of about 200 mm, and a diameter of 30-35 mm, the actual lenses would be on the order of 10-15 times smaller.

10 For the examples of Figs. 2A-K, each of front and rear surfaces 30b and 30g has an aspheric component. For the assembly of Fig. 2L, each of first and fourth cemented surfaces 30c and 30f has an aspheric component. The aspheric components in both instances are characterized by the conic constant k (equal to minus the square of the eccentricity) and aspheric coefficients AD, AE, AF, and AG. For a surface having a base radius R (curvature $c = 1/R$) and tangent to the x-y plane at the origin, the distance z from the x-y plane of a point (x,y) on the surface is 15 given by the following equation:

20

$$z = \frac{c\rho^2}{1 + (1-c^2(k+1)\rho^2)^{1/2}} + AD\rho^4 + AE\rho^6 + AF\rho^8 + AG\rho^{10}$$

25 where $\rho^2 = x^2 + y^2$.

30 Table 1 summarizes the general configuration of the elements of the assemblies of Figs. 2A-L. The element surfaces that are formed with aspherics are denoted by asterisks.

35 The general method of designing five-element assembly 20 may be outlined as follows. First, with the general configuration in mind, reasonable indices of refraction are determined from a choice of suitable materials. For example, the assembly of Fig. 2A has negative elements 25 are formed of a flint glass having a relatively low index of refraction and high

dispersion. End elements 27 are formed of a crown glass having low dispersion and high index. Central element 22 is preferably also formed of a crown glass having a high index and low dispersion. As the optical power of the central element is modest, this preference is not strong. The central element provides strength for the cemented assembly.

Having determined the indices of refraction, and further imposing the requirement that the assembly be symmetric, the powers of the individual elements are determined by requiring the Petzval sum to be reduced to a predetermined desired level and further requiring a given overall power. At this point, the choice of materials may be refined so that the dispersions can be chosen to correct chromatic aberration. Spherical aberration, coma, and astigmatism are not yet corrected. However, the provision of an aspheric surface on end elements 27 corrects spherical aberration, it being noted that with glass molding, it is no more difficult to provide an aspheric surface than a spherical surface. The stop location with respect to cemented surfaces 30c and 30d, together with the distribution between those surfaces is now chosen to correct astigmatism, while coma and distortion are corrected by utilizing a symmetric configuration with two identical axially aligned assemblies defining the transfer module.

The advantages of the design of assembly 20 may be seen. First, while each transfer module comprises ten elements, there are only three different elements, namely two identical central elements, four identical negative elements, and four identical end elements. Furthermore, as described above, the elements may be molded glass. Steep surfaces as are characteristic of sharply bent elements are avoided, and assembly of the overall system is simple.

The above examples also illustrate the flexibility of the design. The examples of Figs. 2A and 2G have the lowest Petzval sum, at the expense of lower speed. Conversely, the example of Fig. 2I is considerably 5 faster, but with a higher Petzval sum. Additionally, the examples of Figs. 2E-F and 2J-L, which are constrained to have flat surfaces are generally slower with higher Petzval sums. The examples of Figs. 2C and 10 2I illustrate the use of polycarbonate plastic rather than flint glass for the negative elements, while the example of Fig. 2D illustrates the use of very high index material for the end elements. Moreover, for the examples of Figs. 2F and 2K, where there is no power at the surfaces of the central element, the central 15 element can have high dispersion, thereby adding to the flexibility of the design.

Fig. 3 is an optical schematic of a transfer module 40 that represents a limiting case of the example of Fig. 2L. The lens parameters are set forth 20 in Appendix 2. The example of Fig. 2L, like all the preceding examples with flat end faces, has the flat faces slightly spaced from the pupil and image planes. With slight modification, the flat end faces can be constrained to lie in the pupil and image planes so 25 that adjacent end faces abut and can be cemented. Alternatively, the two abutting end elements can be formed as a unitary element. Transfer module 40 can be thought of as including a pair of assemblies, with adjacent assemblies sharing a common element. The 30 first assembly includes a central rod-like element 42, negative elements 45, a positive plano-convex front element 47 and the front half of a convex-convex element 48. The geometry is characterized by a front surface 50a (which is also the first image surface), cemented surfaces 50b, 50c, 50d and 50e, and a pupil 35 plane 50f which bisects convex element 48.

Figs. 4A and 4B are optical schematics, each of an assembly 60 where the limiting case relative to the examples of Figs. 2A-L is that the central element and the negative elements are the same material, and thus define a unitary negative rod-like element 62, to which are cemented positive end elements 67. The geometry is characterized by a pupil plane 70a, a front surface 70b (slightly concave in Fig. 4A and flat in Fig. 4B), cemented surfaces 70c and 70d, a rear surface 70e, and an image plane 70f.

Fig. 4C shows a transfer module 80 that represents the limiting case where the flat end faces coincide with the pupil and image planes so that adjacent positive elements merge into unitary elements. Assembly 80 includes a central rod-like element 82 to which are cemented a positive plano-convex front element 87 and the front half of a convex-convex element 88. The geometry is characterized by a flat front surface 80a (which is also the first image surface), cemented surfaces 80b and 80c, and a pupil plane which bisects convex element 88. The lens parameters for the assemblies of Figs. 4A-C are set forth in Appendices 3A-C.

Fig. 5 shows a paired doublet transfer assembly 90. The optical parameters are set forth in Appendix 4.

In conclusion, it can be seen that the present invention provides design for relay optics that is characterized by high levels of correction, manufacturability, and flexibility. While the above gives a description of the preferred embodiments of the invention, various modifications, alternative constructions and equivalents may be employed without departing from the spirit of the invention. Therefore, the above description and illustrations should not be taken as limiting the scope of the invention which is defined by the appended claims.

TABLE 1

<u>Figure(s)</u>	<u>End Elements</u>	<u>Negative Elements</u>	<u>Central Element</u>
2A-D, 2G-I	concave*-convex	concave-concave	convex
2E	plano*-convex	concave-concave	convex
2F	plano*-convex	plano-concave	flat
2J	convex*-convex	concave-concave	convex
2K	concave*-convex	plano-concave	flat
2L	plano-convex*	concave*-concave	convex

10
APPENDIX 1A
(PETZVAL SUM = 0.22)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	-63.111	10.602	Schott LAF21	1.792	47.23
C	-15.873	5.506	Schott LF6	1.570	42.56
D	30.551	165.602	Schott LAF21	1.792	47.23
E	-30.551	5.506	Schott LF6	1.570	42.56
F	15.873	10.602	Schott LAF21	1.792	47.23
G	63.111	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	1.516E+01	-3.126E-06	-5.248E-09	-1.507E-11	0.000E+00
G	1.516E+01	3.126E-06	5.248E-09	1.507E-11	0.000E+00

<u>BF</u>	<u>E/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.008	4.00	399.643	-1.000	12.5	12.5

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

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APPENDIX 1B
 (PETZVAL SUM = 0.71)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	110.974	13.985	Schott LASFN30	1.807	46.13
C	-21.284	3.000	Schott LF7	1.578	41.22
D	37.398	164.099	Schott LAF21	1.792	47.23
E	-37.398	3.000	Schott LF7	1.578	41.22
F	21.284	13.985	Schott LASFN30	1.807	46.13
G	110.974	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AP</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	1.849E+01	-3.019E-06	-3.764E-09	-6.490E-12	0.000E+00
G	1.849E+01	3.019E-06	3.764E-09	6.490E-12	0.000E+00

<u>BF</u>	<u>E/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.017	3.33	400.156	-1.000	15.0	15.0

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

SUBSTITUTE SHEET

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APPENDIX 1C
(PETZVAL SUM = 0.80)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	-128.871	11.396	Schott LASF3	1.813	40.36
C	-21.742	4.000	Polycarbonate	1.590	29.62
D	46.858	167.394	Schott SF57	1.855	23.64
E	-46.858	4.000	Polycarbonate	1.590	29.62
F	21.742	11.396	Schott LASF3	1.813	40.36
G	128.872	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	2.385E+01	-2.563E-06	-2.859E-09	-4.520E-12	0.000E+00
C	2.385E+01	2.563E-06	2.859E-09	4.520E-12	0.000E+00

<u>BF</u>	<u>E/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.022	3.33	400.351	-1.000	15.0	15.0

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

13
APPENDIX 1D
(PETZVAL SUM = 0.60)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	-109.876	14.212	Schott LASFN31	1.886	40.76
C	-23.049	3.000	Schott F5	1.607	37.76
D	35.968	163.663	Schott LAF21	1.792	47.23
E	-35.968	3.000	Schott F5	1.607	37.76
F	23.049	14.212	Schott LASFN31	1.886	40.76
G	109.876	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
	<u>CONSTANT</u>				
B	1.868E+01	-2.400E-06	-2.307E-09	-3.133E-12	0.000E+00
C	1.868E+01	2.400E-06	2.307E-09	3.133E-12	0.000E+00

<u>BF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.006	3.33	400.180	-1.000	15.0	15.0

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

SUBSTITUTE SHEET

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APPENDIX 1E
(PETZVAL SUM = 1.33)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	Flat	12.327	Schott LAFN24	1.761	47.57
C	-24.819	3.000	Schott LF7	1.578	41.22
D	79.030	166.990	Schott LAK10	1.723	50.17
E	-79.030	3.000	Schott LF7	1.578	41.22
F	24.819	12.327	Schott LAFN24	1.761	47.57
G	Flat	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	0.000E+00	-2.490E-06	-2.162E-09	-1.722E-12	0.000E-00
G	0.000E+00	2.490E-06	2.162E-09	1.722E-12	0.000E-00

<u>BF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.0448	3.33	399.3333	-1.000	15.0	15.0

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

15
APPENDIX 1F
(PETZVAL SUM = 1.34)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	Flat	10.188	Schott LASFN30	1.807	46.13
C	-27.271	3.000	Schott TIF3	1.551	41.89
D	Flat	172.759	Schott SF6	1.813	25.24
E	Flat	3.000	Schott TIF3	1.551	41.89
F	27.271	10.188	Schott LASFN30	1.807	46.13
G	Flat	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AP</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	0.000E+00	-2.693E-06	-1.757E-09	-9.843E-13	0.000E-00
G	0.000E+00	2.693E-06	1.757E-09	9.843E-13	0.000E-00

<u>BF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.0588	3.33	402.3318	-1.000	15.0	15.0

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

16
APPENDIX 1G
(PETZVAL SUM = 0.23)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	2.000	Air		
B	-65.414	11.211	Schott LAF21	1.792	47.23
C	-15.949	3.000	Schott LF7	1.578	41.22
D	28.884	167.568	Schott LAF25	1.789	41.04
E	-28.884	3.000	Schott LF7	1.579	41.22
F	15.949	11.211	Schott LAF21	1.792	47.23
G	65.414	2.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	1.687E+01	-2.983E-06	-4.188E-09	-7.958E-12	0.000E-00
G	1.687E+01	2.982E-06	4.188E-09	7.958E-12	0.000E-00

<u>EF</u>	<u>E/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
2.003	4.00	400	-1.000	10.2	10.2

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

17
APPENDIX 1H
(PETZVAL SUM = 0.23)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	-117.681	14.879	Schott LASFN30	1.807	46.13
C	-22.026	3.000	Schott LF7	1.576	41.22
D	37.521	162.605	Schott LAF21	1.792	47.23
E	-37.521	3.000	Schott LF7	1.576	41.22
F	22.026	14.879	Schott LASFN30	1.807	
G	117.681	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	2.453E+01	-2.427E-06	-2.820E-09	-4.759E-12	0.000E-00
G	2.453E+01	2.427E-06	2.820E-09	4.759E-12	0.000E-00

<u>BF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.000	2.78	400	-1.000	15.05	15.05

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

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APPENDIX II
(PET2VAL SUM = 0.77)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	2.000	Air		
B	-125.497	15.740	Schott LASF3	1.813	40.36
C	-22.623	4.000	Polycarbonate	1.590	29.62
D	43.034	157.900	Schott SF57	1.855	23.64
E	-43.034	4.000	Polycarbonate	1.590	29.62
F	22.623	15.740	Schott LASF3	1.813	40.36
G	125.497	2.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	3.323E+01	-1.722E-06	-1.307E-09	-1.208E-12	0.000E-00
G	3.323E+01	2.722E-06	1.307E-09	1.208E-12	0.000E-00

<u>BF</u>	<u>E/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
2.000	2.27	400	-1.000	17.3	17.3

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

SUBSTITUTE SHEET

19
 APPENDIX 1J
 (PETZVAL SUM = 1.22)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	885.300	9.615	Schott LAFN24	1.761	47.57
C	-25.732	3.000	Schott LLF1	1.551	45.47
D	31.395	173.016	Schott BK7	1.519	63.96
E	-31.395	3.000	Schott LLF1	1.551	45.47
F	25.732	9.615	Schott LAFN24	1.761	47.57
G	-885.300	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	0.000E+00	-2.648E-06	-2.041E-09	-1.831E-12	0.000E-00
G	0.000E+00	2.648E-06	2.041E-09	1.831E-12	0.000E-00

<u>BF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.000	4.00	400	-1.000	15.2	15.2

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

20
APPENDIX 1K
(PETZVAL SUM = 1.29)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	-2053.907	9.025	Schott LASFN30	1.807	46.13
C	-24.212	3.046	Schott LF6	1.570	42.56
D	flat	174.460	Schott SF6	1.813	25.24
E	flat	3.046	Schott LF6	1.570	42.56
F	24.212	9.025	Schott LASFN30	1.807	46.13
G	2053.907	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	0.000E+00	-3.396E-06	-2.846E-09	-2.902E-12	0.000E+00
G	0.000E+00	3.396E-06	2.846E-09	2.902E-12	0.000E-00

<u>BF</u>	<u>E/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.000	3.33	400	-1.000	15.3	15.3

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

21
APPENDIX 1L
(PETZVAL SUM = 1.32)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	flat	12.331	Schott LAFN24	1.761	47.57
C	-23.080	3.000	Schott LF7	1.578	41.22
D	117.954	167.765	Schott LAK10	1.723	50.17
E	-117.954	3.000	Schott LF7	1.578	41.22
F	23.081	12.331	Schott LAFN24	1.761	47.57
G	flat	1.000	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
C	-5.747E+00	6.992E-06	1.247E-09	0.000E-12	0.000E-00
F	-5.747E+00	-6.992E-06	-1.247E-09	0.000E-12	0.000E-00

<u>BF</u>	<u>E/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.000	3.33	400	-1.000	15.5	15.5

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

22
APPENDIX 2
(PETZVAL SUM = 1.33)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	flat				
B	-23.358	14.312	Schott LAFN24	1.761	47.57
C	102.675	3.000	Schott LF7	1.578	41.22
D	-102.675	165.773	Schott LAK10	1.723	50.17
E	23.358	3.000	Schott LF7	1.578	41.22
F	-	14.312	Schott LAFN24	1.761	47.56

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	-5.748E+00	6.755E-06	1.104E-09	0.000E-00	0.000E+00
E	-5.748E+00	-6.755E-06	-1.104E-09	0.000E-00	0.000E+00

<u>RF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
0.000	3.33	400	-1.000	15.16	15.16

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

23
APPENDIX JA
(PETZVAL SUM = 1.19)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	-55947	10.692	Schott LAFN28	1.777	49.33
C	-24.770	177.057	Schott LF6	1.570	42.56
D	24.770	10.692	Schott LAFN28	1.777	49.33
E	55947	1.000	Air		
F	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	0.000E+00	-2.814E-06	-2.353E-09	-2.578E-12	0.000E+00
E	0.000E+00	2.814E-06	2.353E-09	2.578E-00	0.000E+00

<u>BF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.000	3.57	400	-1.000	16.27	16.27

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

24
APPENDIX 3B
(PETZVAL SUM = 1.18)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-	1.000	Air		
B	Flat	12.833	Schott LASFN30	1.807	46.13
C	-24.328	166.930	Schott F8	1.599	33.91
D	24.328	12.833	Schott LASFN30	1.807	46.13
E	Flat	1.000	Air		
F	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
C	-6.183E+01	5.836E-06	5.973E-10	0.00E-12	0.000E+00
D	-6.183E+01	-5.836E-06	-5.973E-10	0.00E-00	0.000E+00

<u>BF</u>	<u>E/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
1.000	3.33	400	-1.000	16.80	16.80

<u>WAVL NBR</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

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25
APPENDIX 3C
(PETZVAL SUM = 1.19)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	flat				
B	-24.138	14.597	Schott LASFN320	1.807	46.13
C	24.138	171.701	Schott F8	1.599	38.91
D	flat	14.597	Schott LASFN30	1.807	46.13

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	-6.450E+01	5.718E-06	4.678E-10	0.000E-00	0.000E+00
C	-6.450E+01	-5.718E-06	-4.678E-10	0.000E-00	0.000E+00

<u>BF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
0.000	3.33	400	-1.000	16.52	16.52

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

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26
APPENDIX 4
(PETZVAL SUM = -0.28)

<u>SURFACE</u>	<u>RADIUS</u>	<u>THICKNESS</u>	<u>MEDIUM</u>	<u>INDEX</u>	<u>ABBE NO.</u>
A	-				
B	142.090	0.600	Air		
C	-27.780	6.000	Schott LASFN31	1.886	40.76
D	50.246	2.874	Schott TIFN5	1.598	35.24
		181.032	Air		
E	-50.246	2.874	Schott TIFN5	1.598	35.24
F	27.780	6.000	Schott LASFN31	1.886	40.76
G	-142.090	0.600	Air		
H	-				

<u>SURF</u>	<u>CONIC CONSTANT</u>	<u>AD</u>	<u>AE</u>	<u>AF</u>	<u>AG</u>
B	0.000E+00	-3.395E-06	-2.392E-09	-1.628E-12	0.000E-00
G	0.000E+00	3.395E-06	2.392E-09	1.628E-12	0.000E+00

<u>BF</u>	<u>F/NBR</u>	<u>OID</u>	<u>T-MAG</u>	<u>REF OBJ HT</u>	<u>REF AP HT</u>
0.600	7.14	399.958	-1.000	14.53	14.53

WAVL NBR	1	2	3	4	5
WAVELENGTH	0.5461	0.4800	0.6438	0.0000	0.0000
SPECTRAL WT	1.0000	1.0000	1.0000	1.0000	1.0000

CLAIMS

1. A lens assembly for incorporation into an optical transfer system wherein two such assemblies define an optical transfer module for transferring an image between successive image planes, comprising:

5 a rod-like central element constructed of a first material having a relatively high index of refraction and having first and second surfaces;

10 first and second negative elements constructed of a second material having a relatively low index of refraction, being axially spaced apart from each other by said central element and being cemented to said first and second ends;

15 first and second positive elements constructed of a third material having a relatively high index of refraction, being spaced apart from each other by said central element and said negative elements and being cemented to said negative elements;

20 the dispersions of said first, second, and third materials being chosen to substantially correct chromatic aberration;

the index difference contribution to the Petzval sum dominating the bending and spacing contributions to the Petzval sum contribution.

25 2. The lens assembly of claim 1 wherein said positive elements are substantially identical, said negative elements are substantially identical, and said central element is substantially symmetric about a median plane, thereby substantially correcting coma, distortion, and lateral color.

30 35 3. The lens assembly of claim 1 wherein said central element has convex surfaces, said negative elements are concave-concave, and said positive elements are concave-convex.

28

4. The lens assembly of claim 1 wherein said central element and said positive elements are formed of the same material.

5 5. The lens assembly of claim 1 wherein said central element and said positive elements are formed of different materials.

6. The lens assembly of claim 1 as in
Appendix 1A.

10

7. The lens assembly of claim 1 as in
Appendix 1B.

15 8. The lens assembly of claim 1 as in
Appendix 1C.

9. The lens assembly of claim 1 as in
Appendix 1D.

20

10. The lens assembly of claim 1 as in
Appendix 1E.

25

11. The lens assembly of claim 1 as in
Appendix 1F.

30

12. The lens assembly of claim 1 as in
Appendix 1G.

35

13. The lens assembly of claim 1 as in
Appendix 1H.

14. The lens assembly of claim 1 as in
Appendix 1I.

35

15. The lens assembly of claim 1 as in
Appendix 1J.

29

16. The lens assembly of claim 1 as in
Appendix 1K.

17. The lens assembly of claim 1 as in
Appendix 1L.

5

18. The lens assembly as in Appendix 2.

19. The lens assembly as in Appendix 3A.

10

20. The lens assembly as in Appendix 3B.

21. The lens assembly as in Appendix 3C.

22. The lens assembly as in Appendix 4.

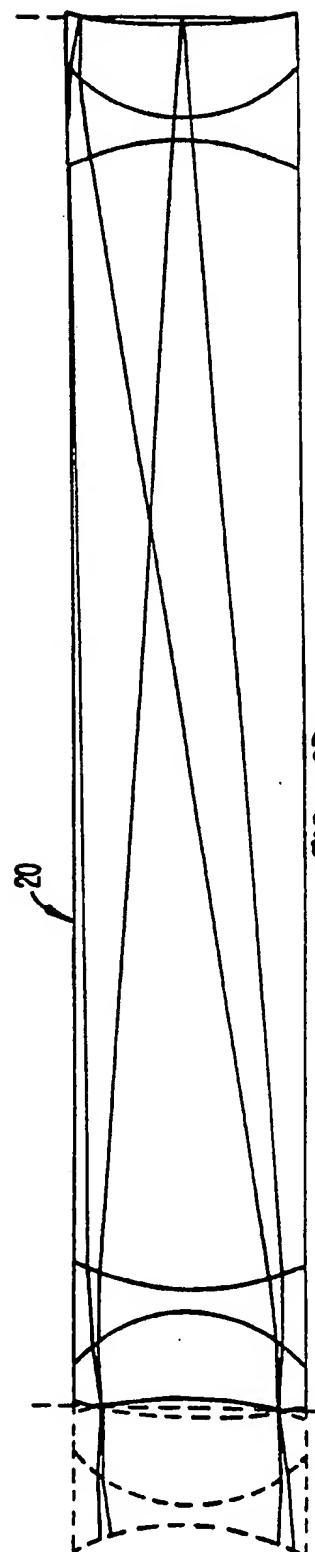
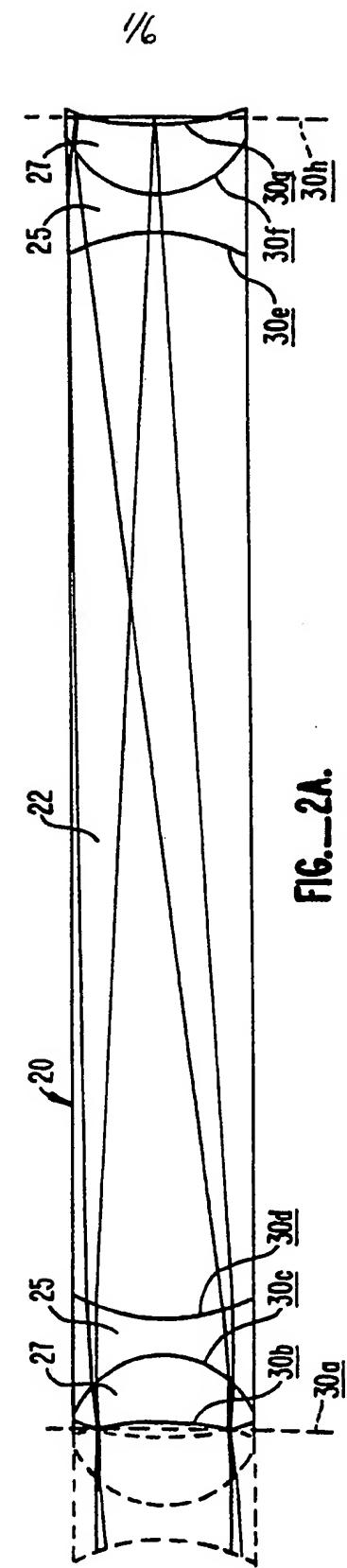
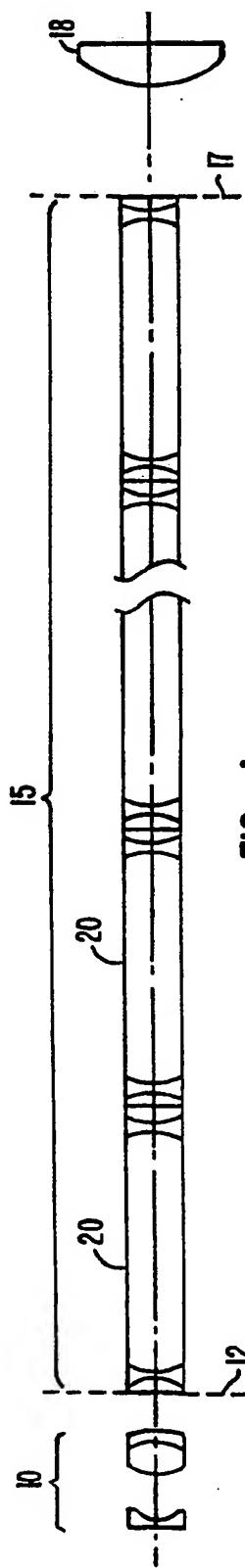
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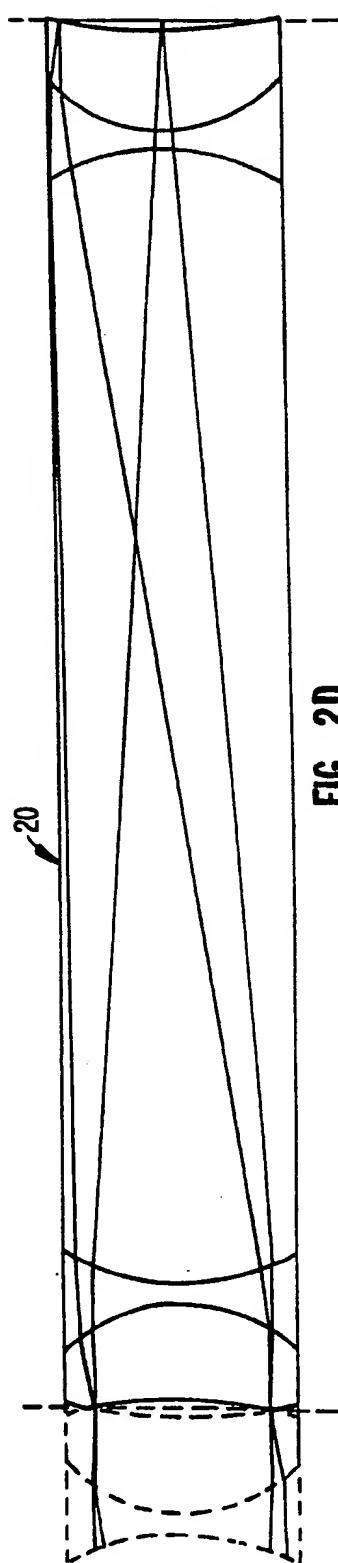
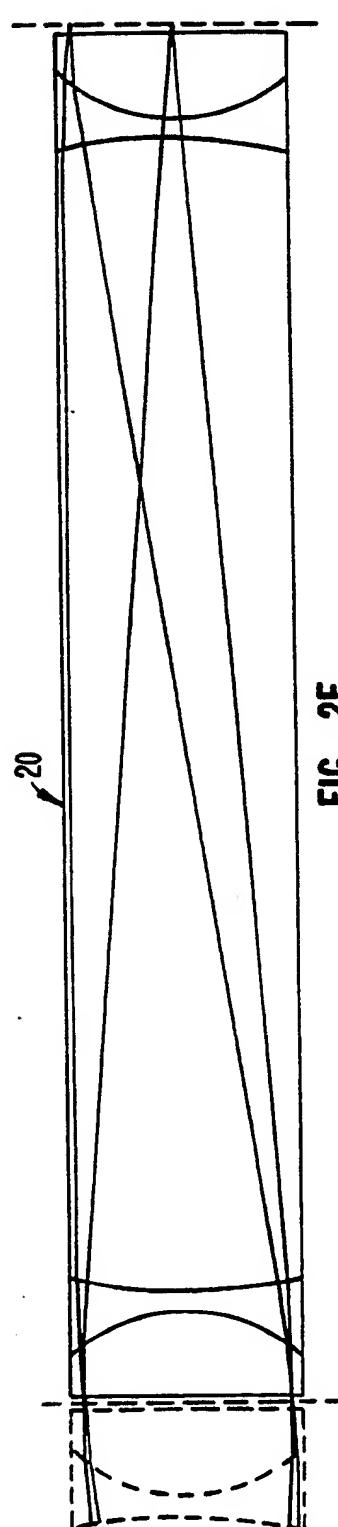
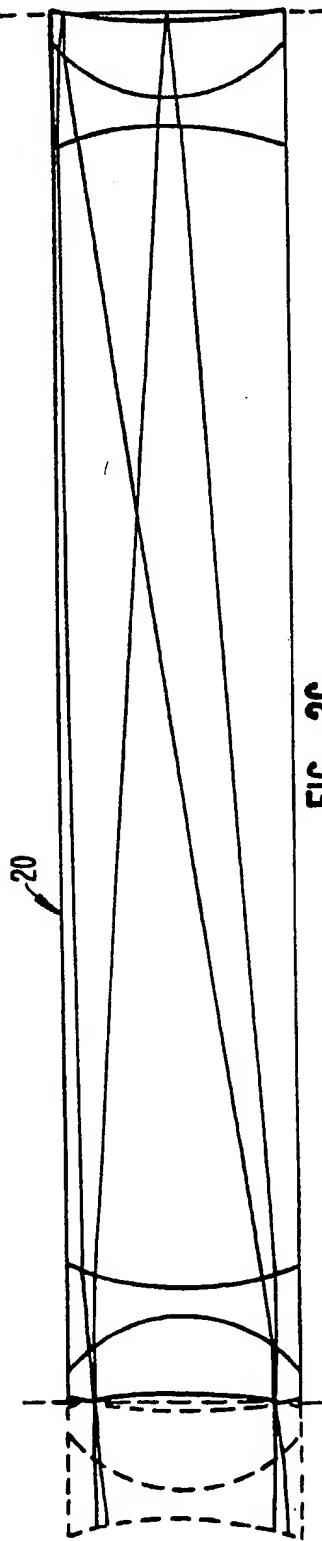
25

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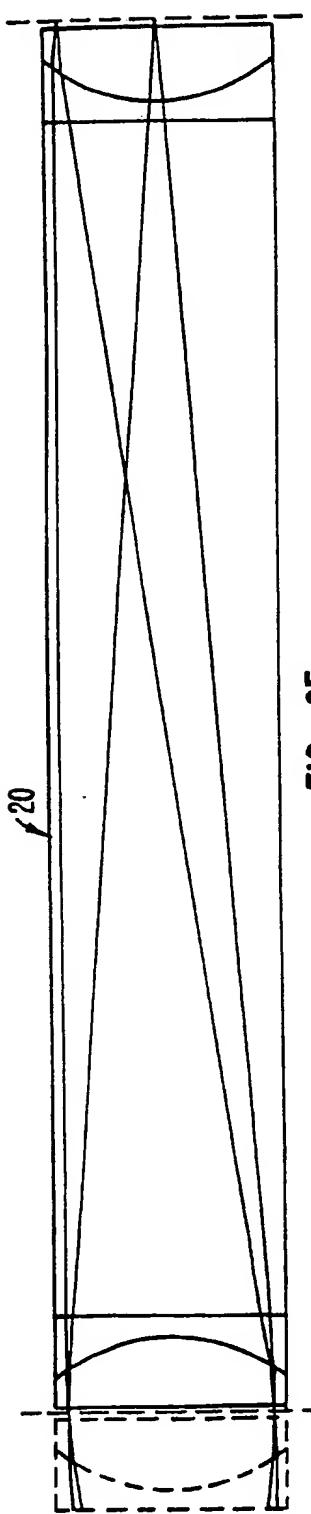


FIG._2F.

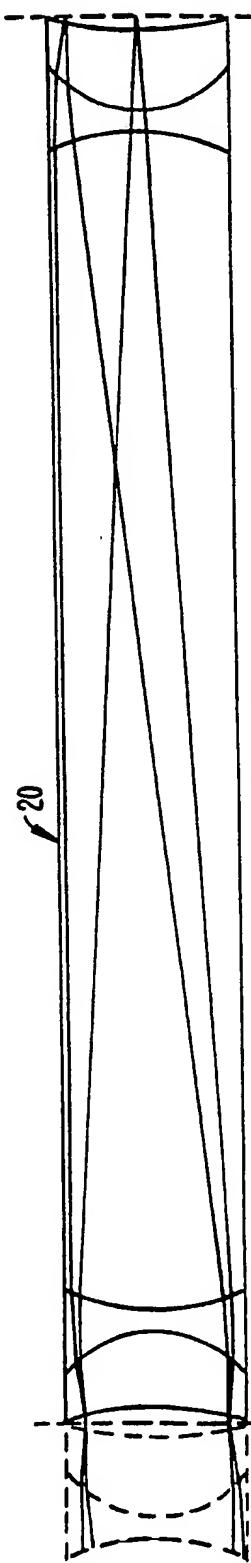


FIG._2G.

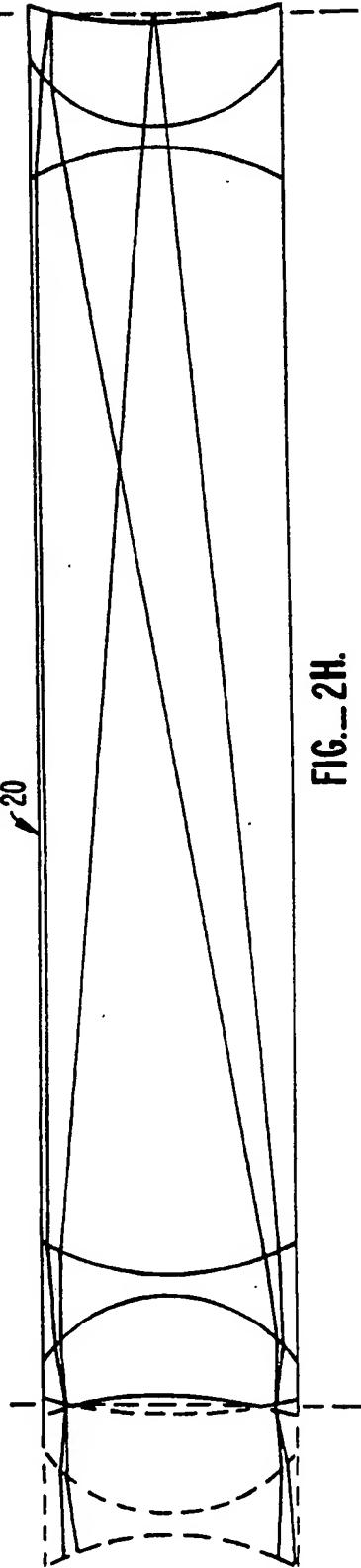
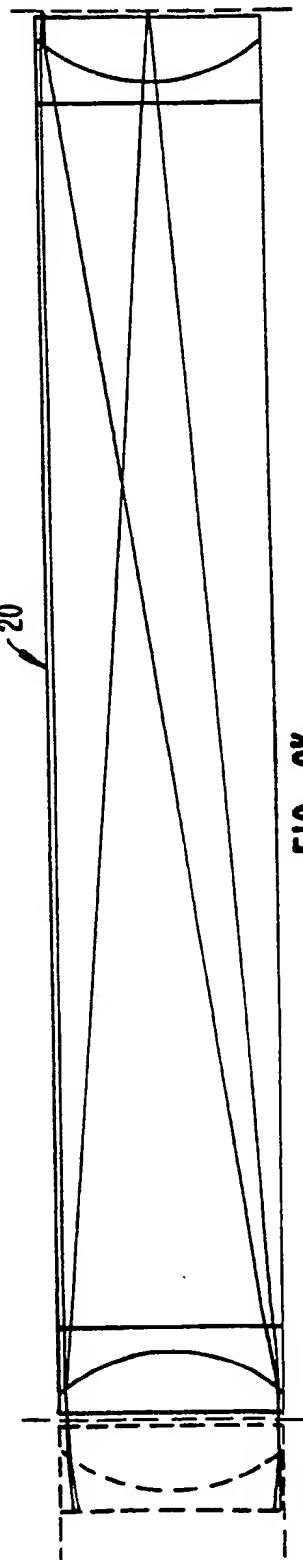
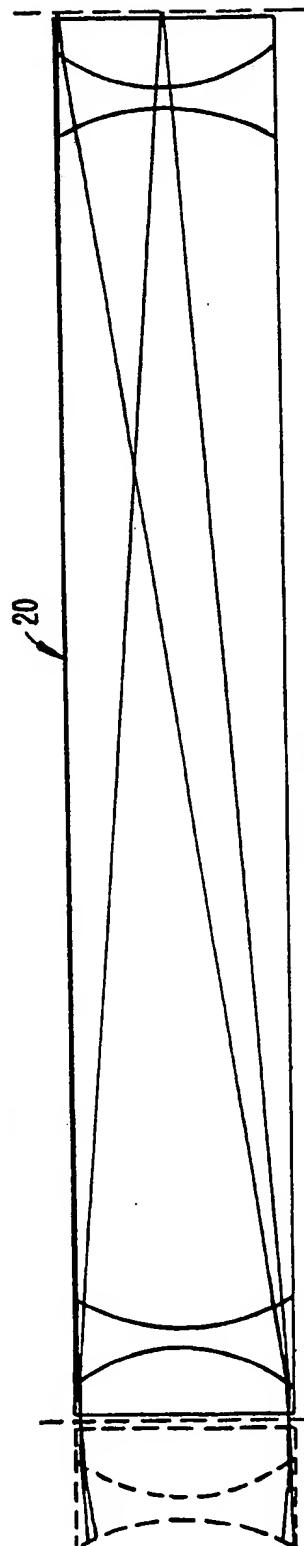
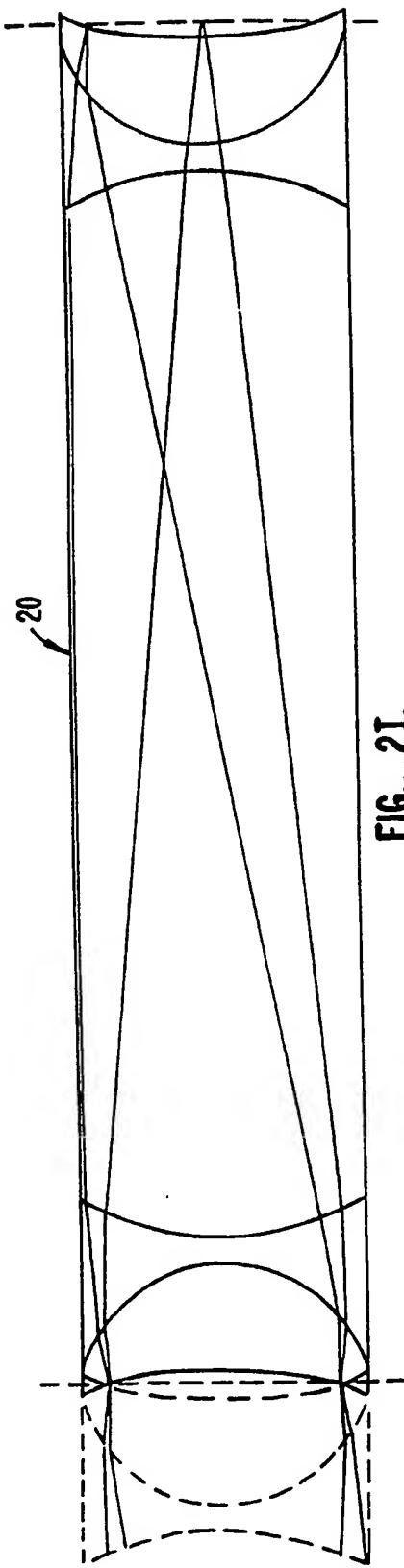


FIG._2H.



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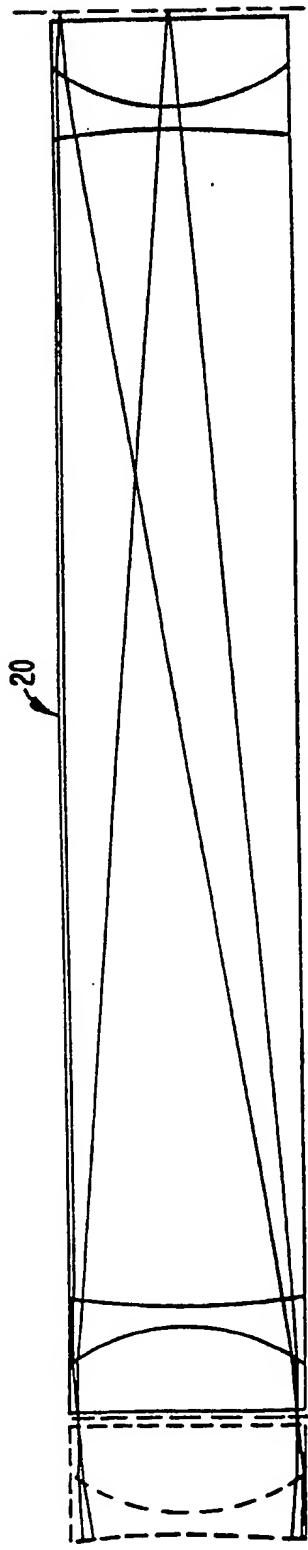


FIG. - 2L.

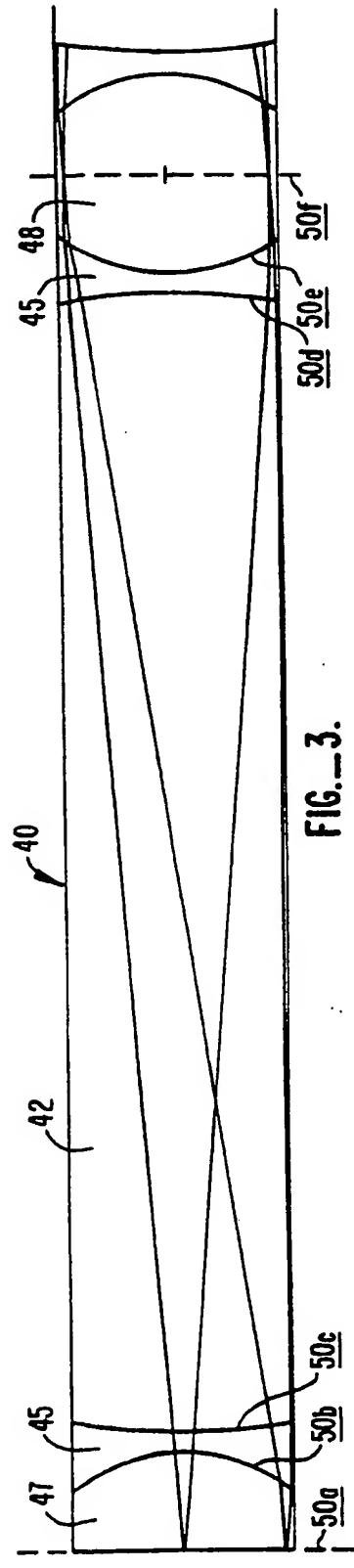


FIG. - 3.

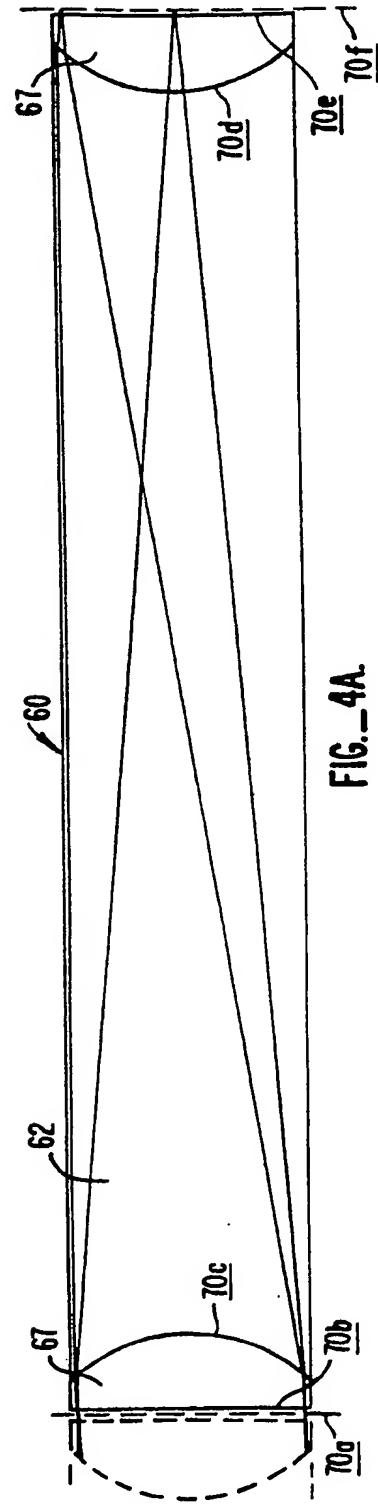


FIG. - 4A.

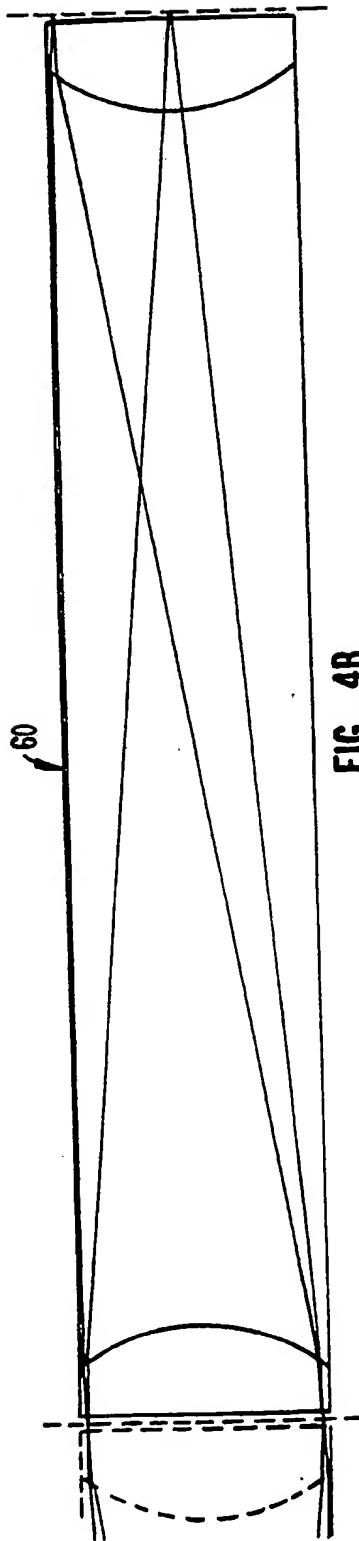


FIG.-4B.

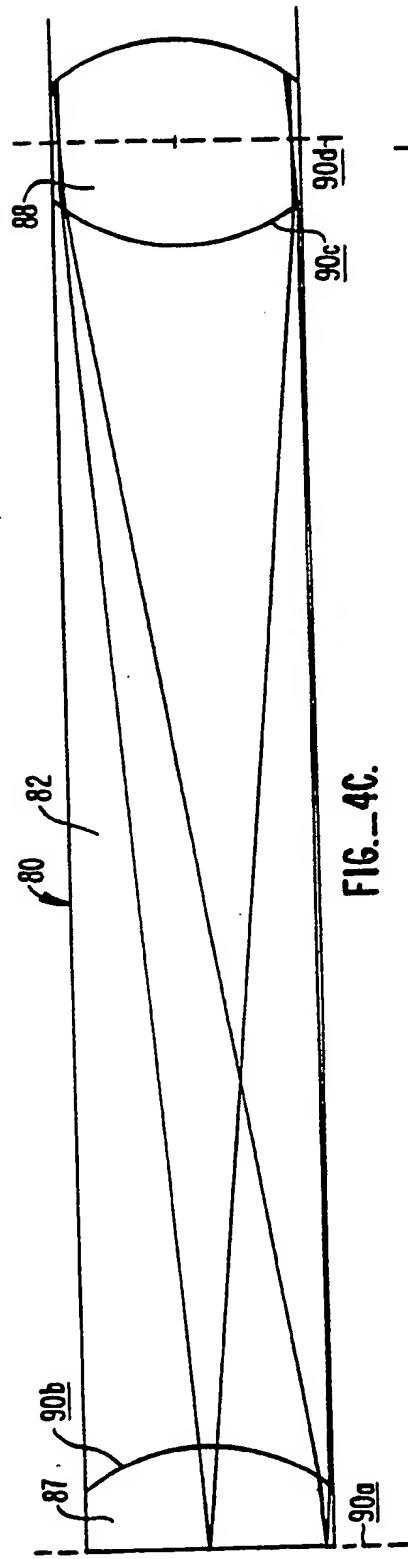


FIG.-4C.

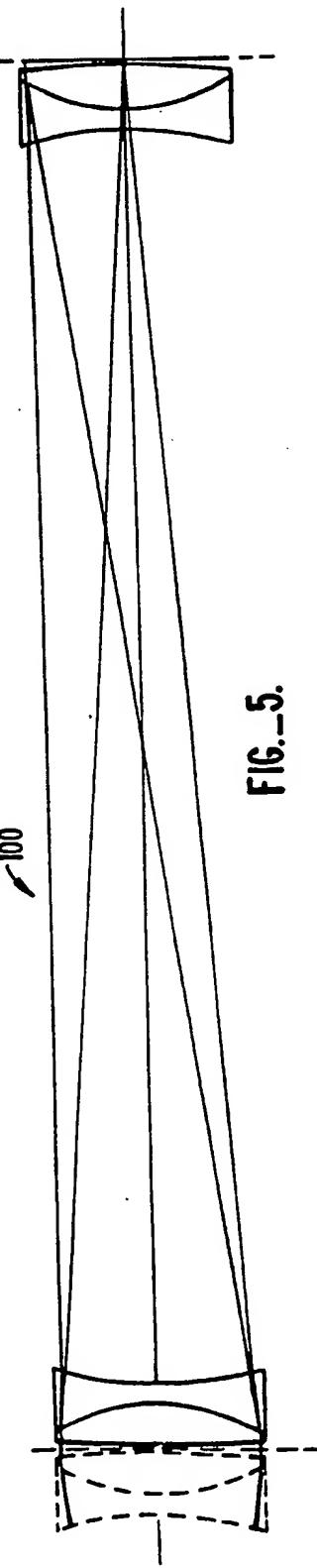


FIG.-5.

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US89/01847

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. C1⁴ G02B 23/24, 9/60, 9/36, 13/18, 21/02

U.S. CL. 350/573, 572, 465, 470, 432, 413, 414, 447, 475

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷

Classification System	Classification Symbols
U.S.	350/573, 572, 465, 470, 432, 413, 414, 447, 475

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched ⁶

III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹

Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
Y	US, A, 4,575,195 (HOOGLAND) 11 March 1986 (11.03.86) (see column 8, lines 13-39 and Appendix 5).	1-3, 5
Y	US, A, 4,545,652 (HOOGLAND) 8 October 1985 (08.10.86) (see column 8, lines 13-39 and (Appendix 5).	1-3, 5
Y,P	US, A, 4,783,154 (TAKAHASHI) 8 November 1988 (see column 1, lines 45-51, column 3, lines 19-50, column 11, lines 25-36).	1-3, 5

* Special categories of cited documents: ¹⁰

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

20 July 1989

Date of Mailing of this International Search Report

18 SEP 1989

International Searching Authority

ISA/US

Signature of Authorized Officer

Jon W. Henry

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